TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 561

FULL-SCALE WIND-TUNNEL TESTS TO DETERMINE A SATISFACTORY LOCATION FOR A SERVICE PITOT-STATIC TUBE ON A LOW-WING MONOPLANE

By John F. Parsons
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SUMMARY

Surveys of the air flow over the upper surface of four different airfoils were made in the full-scale wind tunnel to determine a satisfactory location for a fixed pitot-static tube on a low-wing monoplane. The selection was based on small interference errors, less than 5 percent, and on a consideration of structural and ground-handling problems. The most satisfactory location on the airfoils without flaps that were investigated was 10 percent of the chord aft and 25 percent of the chord above the trailing edge of a section approximately 40 percent of the semispan inboard of the wing tip. No satisfactory location was found near the wing when the flaps were deflected.

INTRODUCTION

The location of the air-speed head or pressure element of an air-speed indicator is of considerable importance if it is to record accurately the speed of the airplane relative to the undisturbed air. In general, the practice with low-wing monoplanes has been to locate the pressure element immediately in front of the airfoil. Although it is evident that this position is probably the most convenient, it is also known that for this position the interference effect of the wing is considerable. By reason of the velocity field set up by the motion of the airplane through the air, there probably is no position immediately adjacent to the airplane at which the pressure at the air-speed head will not be affected for some attitude of flight. In order to prevent damage in ground handling and to simplify the supporting structure, the element should be installed near the airplane in a protected

location at which the installation error will be small for all attitudes of flight.

The results of previous related investigations (references 1, 2, and 3) are in casual agreement and indicate that the most likely location is somewhat aft and above the trailing edge of the airfoil at a section inboard from the wing tip.

At the request of the Bureau of Aeronautics, Navy Department, tests were conducted in the full-scale wind tunnel to determine the best serviceable location on a low-wing monoplane for the air-speed head. Air-flow surveys were accordingly made over the upper surfaces of four different airfoils in a plane approximately 40 percent of the semispan inboard of the wing tip. In addition, surveys were made to determine the feasibility of a wing-tip mounting such as that described in reference 4.

APPARATUS AND TESTS

The tests conducted were in the form of surveys made in the full-scale wind tunnel with the survey equipment. (See reference 5.) The pressure element used in the surveys was an N.A.C.A. type, hemispherical-nose pitot-static tube. These surveys were made over the upper surfaces of four different airfoils: a U.S.A. 45 airfoil of elliptical plan form mounted on a mock-up of a YO-31A airplane (fig. 1); a 2:1 tapered U.S.A. 45 airfoil (fig. 2); a rectangular N.A.C.A. 23012 airfoil (fig. 3); and an N-22 airfoil equipped with a 30 percent chord Zap flap mounted on a Fairchild 22 airplane (fig. 4). The hinge axis of the flap was at 80 percent of the wing chord and the flap angle was 59° when the flap was open.

Surveys were made with the airfoils at 0° yaw and 0° roll and at four angles of attack, covering the normal-flight range, for each airfoil and for the open and closed flap positions on the N-22 airfoil. The surveys consisted of the measurement at numerous points in a plane parallel to the direction of air flow and to the plane of symmetry of the airfoils of the dynamic pressure indicated by a pitot-static tube whose axis was at all times parallel to the airfoil chord. The surveys of the elliptical wing were made at three lateral stations, an inboard station approximately 40 percent of the semispan from the wing

tip, and at stations approximately 4 percent of the semispan inboard and outboard of the tip. As the air-speed head would be subject to damage in ground handling for all the locations near the wing tip in which the installation error is small, the surveys of the remaining airfoils were confined to the inboard station, approximately 40 percent of the semispan from the wing tip. All surveys were run at an air speed of approximately 55 miles per hour, or at an average Reynolds Number of approximately 3,350,000.

A typical test set-up is shown in figure 5. Table I gives the section ordinates of the various airfoils at the survey stations.

RESULTS

The results of a portion of the surveys, those for the highest and lowest angles of attack tested, are shown plotted in contour form in figures 6 to 19. The contours are representative of values of q/q_{true} (the ratio of the indicated dynamic pressure at the survey point to the dynamic pressure of the undisturbed air flow) and are plotted for the position of the survey points in percentage of the wing chord. The coordinate axes are parallel and perpendicular to the airfoil chord with their origin at the trailing edge. Summary curves presenting the results for each wing throughout the angle-of-attack range investigated are given in figures 20 to 25. These summary curves show the contour $q/q_{true} = 1.00$ and the area in which the installation error does not exceed ±5 percent. Figure 26 is a composite curve showing the area common to all the airfoils at all the angles of attack investigated in which the installation error is within ±5 percent.

DISCUSSION

The values of q as measured are approximately correct although some angularity of the air flow may exist; i.e., by reason of compensating errors in the total and static pressures, the calibration of the pitot-static tube used is little affected by pitch (approximately 1 percent error in q for 20° pitch). Although the direction of air flow relative to the air-speed head has not been determined for this investigation, it appears from other tests (reference 1) that this angularity would not exceed 10°

for the regions in which satisfactory installations could be made. For service heads insensitive to an angularity of this order, these results are directly applicable. For heads in which pitch materially affects the calibration, consideration should be given to the angularity of the air flow for the specific case. The static pressure may be somewhat in error even though q is correct.

The surveys made outboard of the wing tip (figs. 6, 7, and 20) show a region forward of the wing tip in which the installation error is less than ±5 percent. An installation in this unprotected area would be unsatisfactory, however, because of the possibility of damage in ground handling.

The possibility of a satisfactory installation of a fixed pitot-static tube at a small distance inboard of the wing tip is remote, as may be seen by inspection of figures 8, 9, and 21. The effect of the wing-tip vortex seems to preclude any satisfactory location in this region.

The inboard surveys (figs. 10 to 17) show much less movement of the contour $q/q_{true} = 1.00$ with an increase in angle of attack than do the surveys at the wing tip and indicate the possibility of some location aft of the airfoil common to all the airfoils tested at which the interference error would be less than 5 percent.

The surveys for the N-22 airfoil with the 30 percent chord Zap flap in the open position (figs. 18 and 19) when compared with the surveys with the flap closed (figs. 16 and 17) show the effect of the flap on the contours of q/q_{true}. These surveys show that no likely position adjacent to the airfoil was found. It is interesting to note, however, that for the position chosen as satisfactory for the airfoils without flaps, the ratio of q/q_{true} remains constant (1.41) for all values of the angle of attack for the flap-down condition.

Summary curves for the inboard station surveys on the airfoils tested are given in figures 22 to 25. These curves show the area in which a satisfactory installation could be made for the angle-of-attack range investigated. It is obvious that a considerable area aft and above the trailing edge of the airfoil is available for a location at which the interference or installation error is less than ±5 percent, an arbitrary value considered to be the limit for a satisfactory installation.

The summary curves of figures 22 to 25 have been grouped into one composite figure (fig. 26) to show the available area at an inboard station in which a satisfactory installation could be made. The solid line of figure 26 approximates the median line of this area. The results of previous investigations (references 1, 2, 3, and unpublished results of flight tests conducted by the N.A.C.A.) are also plotted in figure 26 and lie within the area shown to be satisfactory by this investigation.

From the present investigation it can therefore be concluded that, for the airfoils tested, a satisfactory location for the air-speed head or pressure element of an air-speed indicator is at a section approximately 40 percent of the semispan inboard of the tip and 10 percent of the section chord aft and 25 percent of the section chord above the trailing edge of this section. In the installation of a service head at this location, the effect of pitch upon the calibration of the individual head must be considered. This installation position seems to offer no particular difficulty from structural considerations. In order further to eliminate the possibility of damage while on the ground, the element might be hinged to permit folding over the wing. The proximity of the ailerons to the location chosen as satisfactory by this investigation may cause an error in the air-speed reading upon aileron deflection. The effect of a momentary deflection of the ailerons will probably be negligible; however, for a sustained aileron deflection, as in a sideslip, an error in the indicated air speed will doubtless result.

CONCLUSIONS

1. When interference errors as well as structural and ground-handling problems are considered for the airfoils tested, a satisfactory location for the air-speed head or pressure element of an air-speed indicator on a low-wing monoplane would be 10 percent of the chord aft and 25 percent of the chord above the trailing edge of a section approximately 40 percent of the semispan inboard of the wing tip.

2. The effect of the wing-tip vortex and the possibility of damage in ground handling seems to render inadvisable any installation of the air-speed head near the wing tip.

3. The effect of the split trailing-edge flap on the velocity field around the airfoil is to increase the velocity above and aft of the wing and thereby to permit of no satisfactory location adjacent to the airfoil.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 28, 1936.

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2. Bryant, L. W., and Williams, D. H.: An Investigation of the Flow of Air Around an Aerofoil of Infinite Span. R. & M. No. 989, British A.R.C., 1924.

3. Beij, K. Hilding: Aircraft Speed Instruments. T.R. No. 420, N.A.C.A., 1932.

4. Anon.: The Comper "Mouse" Commercial Airplane (British). A Three-Seat Cabin Low-Wing Monoplane. A.C. No. 184, N.A.C.A., 1933.

5. DeFrance, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. T.R. No. 459, N.A.C.A., 1933.

TABLE I

SECTION ORDINATES AT SURVEY STATIONS

{Section ordinates in percentage of chord}

{Stations in percentage of chord from L. E.}

Airfoil.....	Elliptical plan form U. S. A. 45				2:1 tapered U. S. A. 45		Rectangular N. A. C. A. 23012		N-22 with Zap flap	
Size.....	7.38 (mean chord) by 45.75 ft.				7.38 (mean chord) by 45.75 ft.		6 by 36 ft.		5.21 (mean chord) by 32.83 ft.	
Survey station from airfoil center line.	13 ft. 3/4 in.		22 ft. 3/4 in.		13 ft. 0 in.		11 ft. 0 in.		9 ft. 4 in.	
Chord.....	8 ft. 3-13/32 in.		3 ft. 5-15/32 in.		7 ft. 2-1/32 in.		6 ft. 0 in.		5 ft. 6 in.	
Station	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
0	1.76	1.76	1.54	1.54	1.63	1.63	-	0	3.36	3.36
1.25	4.12	.36	2.87	.41	3.95	.23	2.67	-1.23	5.60	1.80
2.5	5.51	-.09	3.52	.19	5.37	-.24	3.61	-1.71	6.60	1.36
5	7.66	-.64	4.53	-.14	7.60	-.80	4.91	-2.26	8.40	.68
7.5	9.16	-.97	5.33	-.31	9.19	-1.10	5.80	-2.61	9.50	.36
10	10.29	-1.21	5.89	-.46	10.29	-1.37	6.43	-2.92	10.32	.18
15	11.77	-1.54	6.66	-.75	11.80	-1.74	7.19	-3.50	11.44	.06
20	12.60	-1.72	7.19	-.92	12.72	-1.88	7.50	-3.97	12.19	.00
25	12.86	-1.83	7.55	-1.06	12.94	-1.98	7.60	-4.28	12.55	.02
30	12.64	-1.91	7.67	-1.13	12.74	-2.06	7.55	-4.46	12.62	.08
40	11.73	-1.95	7.60	-1.18	11.70	-2.09	7.14	-4.48	12.12	.20
50	10.31	-1.90	7.00	-1.11	10.30	-2.02	6.41	-4.17	11.36	.28
60	8.62	-1.72	6.05	-1.01	8.61	-1.84	5.47	-3.67	9.76	.32
70	6.70	-1.41	4.85	-.84	6.66	-1.55	4.36	-3.00	7.86	.26
80	4.63	-1.02	3.43	-.68	4.58	-1.12	3.08	-2.16	5.64	.14
90	2.37	-.58	1.86	-.46	2.42	-.71	1.68	-1.23	3.20	.04
95	1.22	-.32	1.06	-.36	1.27	-.42	.92	-.70	1.50	.06
100	.10	-.10	.22	-.22	.14	-.14	-	0	.24	.24

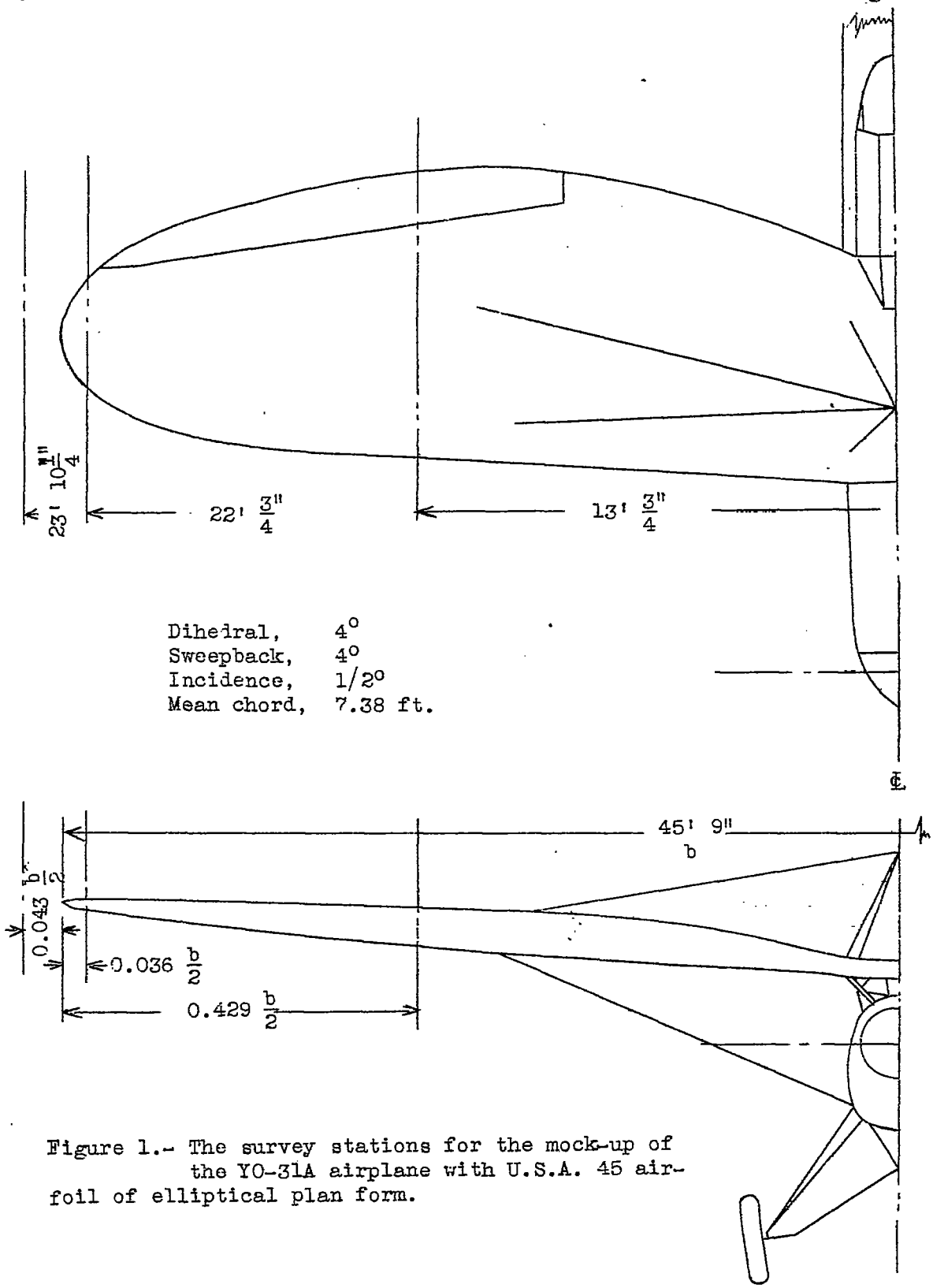
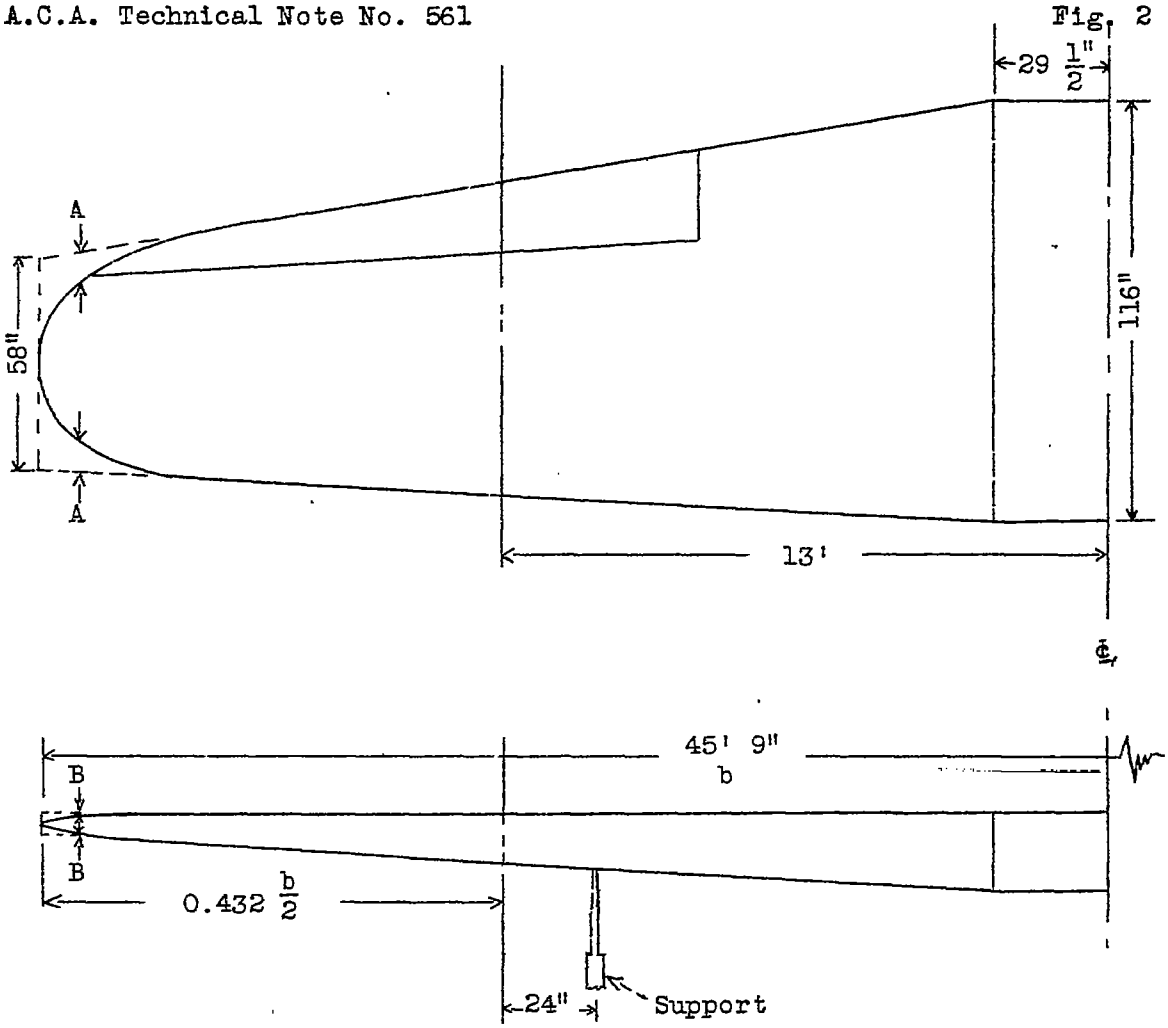


Figure 1.- The survey stations for the mock-up of the YO-31A airplane with U.S.A. 45 airfoil of elliptical plan form.



Station	Chord	A	B
234.5	67.47	0	0
244.5	63.70	.52	.05
254.5	56.40	2.88	.35
264.5	43.40	8.20	1.20
274.5	0	29.00	3.15
Dimensions in inches			

Mean chord, 7.38 ft.

Figure 2.- The survey station for the 2:1 tapered U.S.A. 45 airfoil.

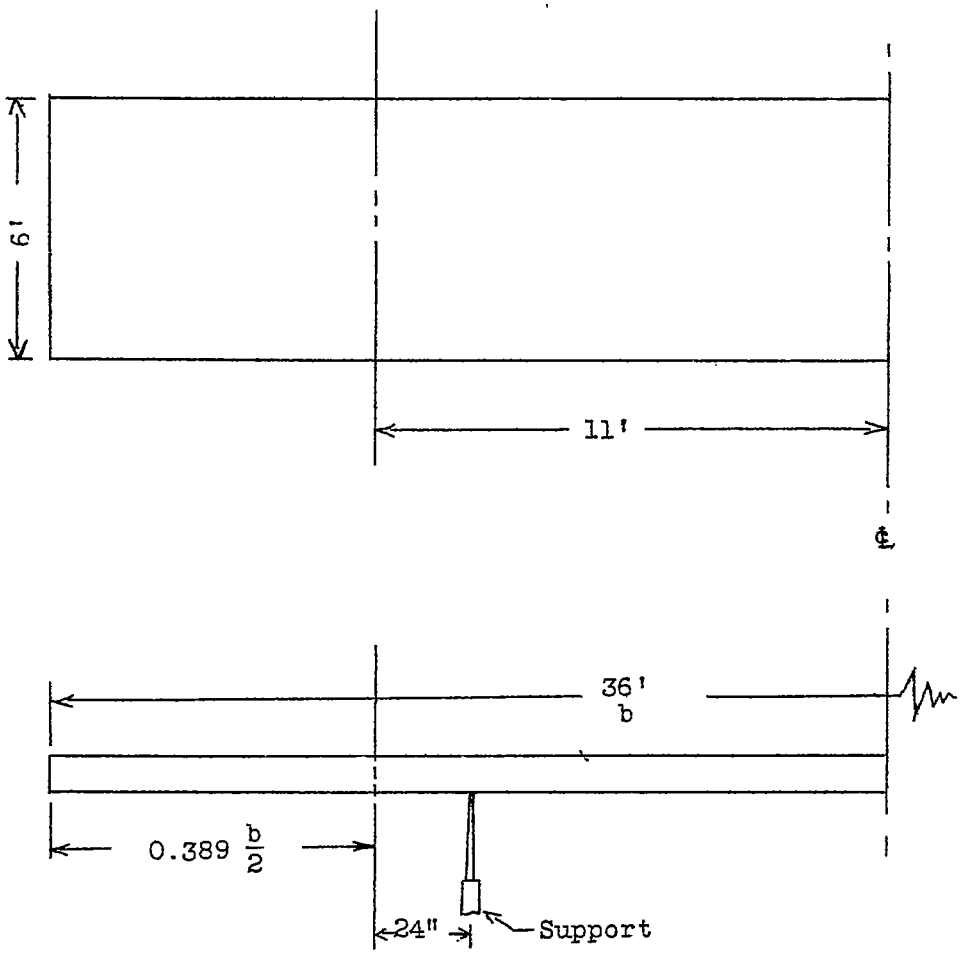


Figure 3.- The survey station for the N.A.C.A. 23012 airfoil.

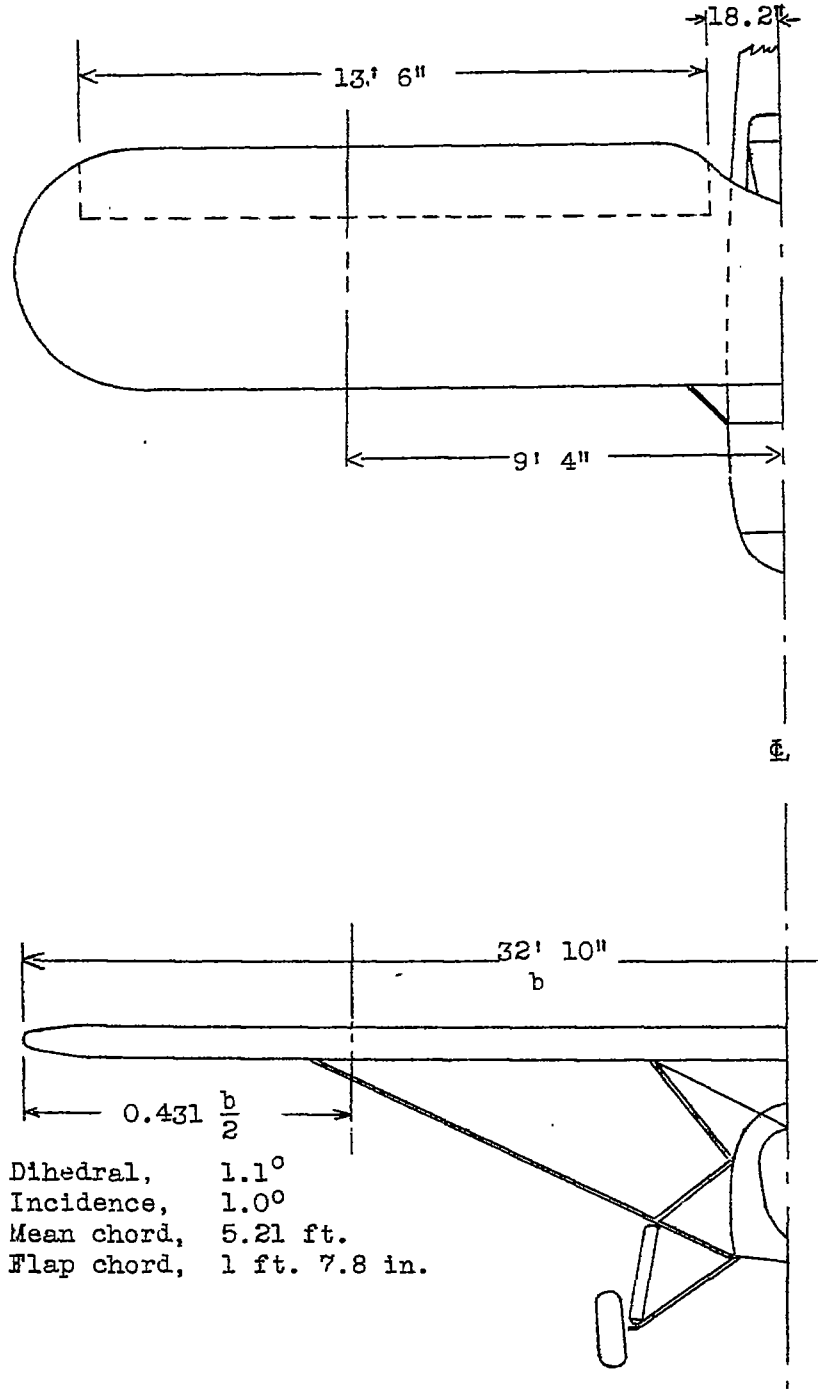


Figure 4.- The survey station for the Fairchild 22 with N-22 airfoil and Zap flap.

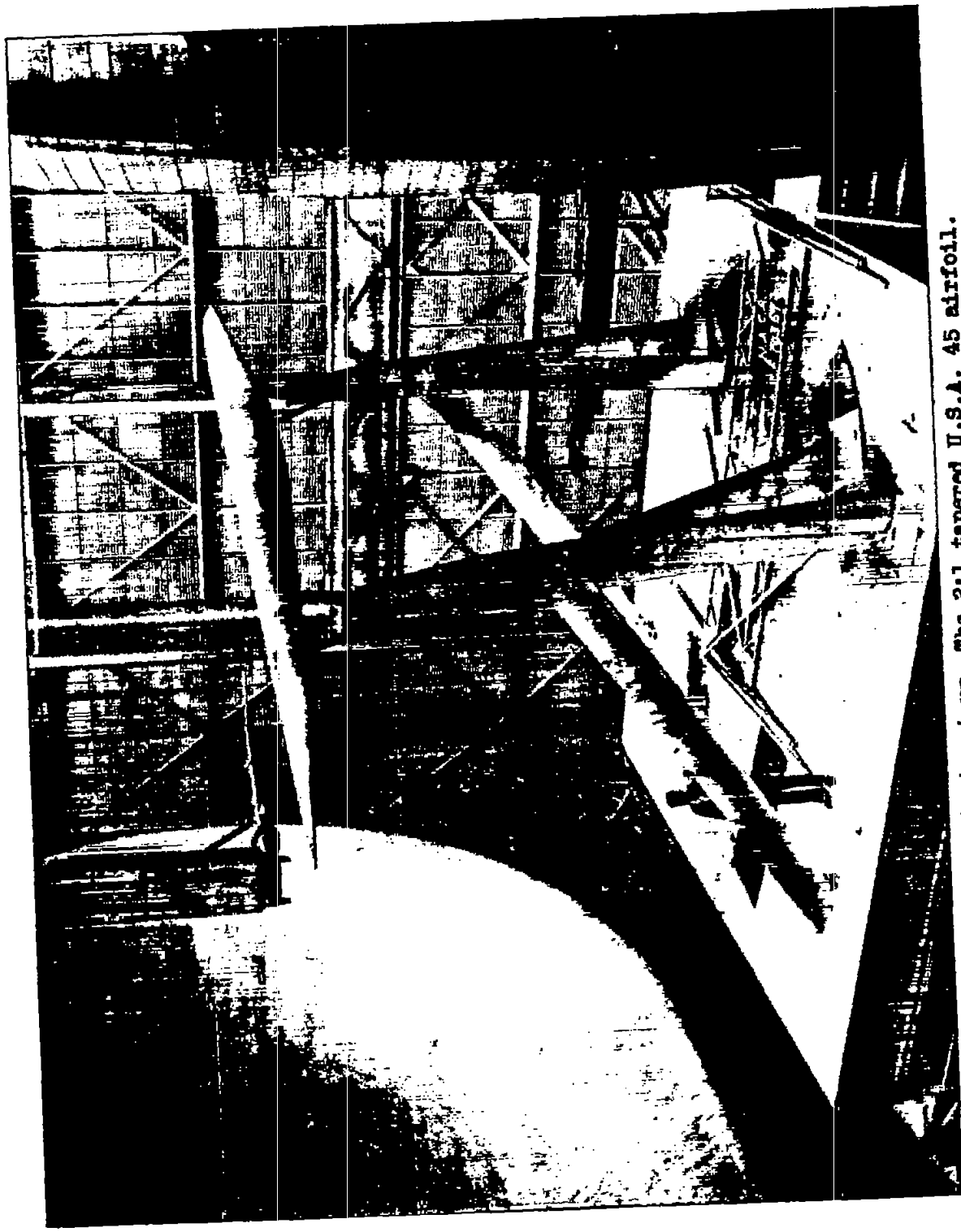


Figure 5.- Typical test set-up. The 2:1 tapered U.S.A. 45 airfoil.

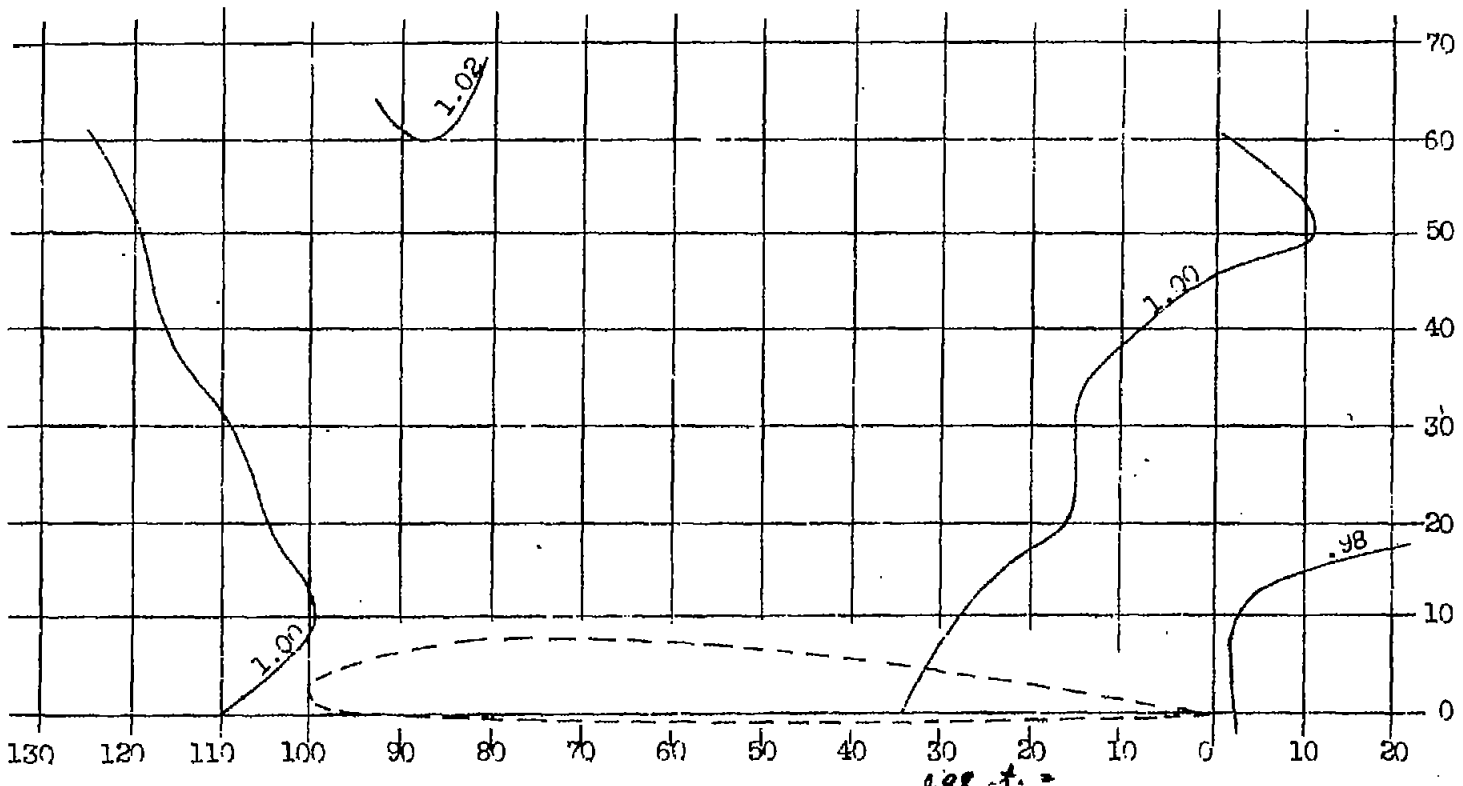


Figure 6.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.043 semispan outboard of wing tip. Coordinates in percentage of chord at station 0.036 semispan inboard of wing tip, chord 3 ft. 5 15/32 in. Pitot axis parallel to wing chord. Contours of q/q_{true}, $\alpha = -0.4^{\circ}$, $C_L = 0.153$

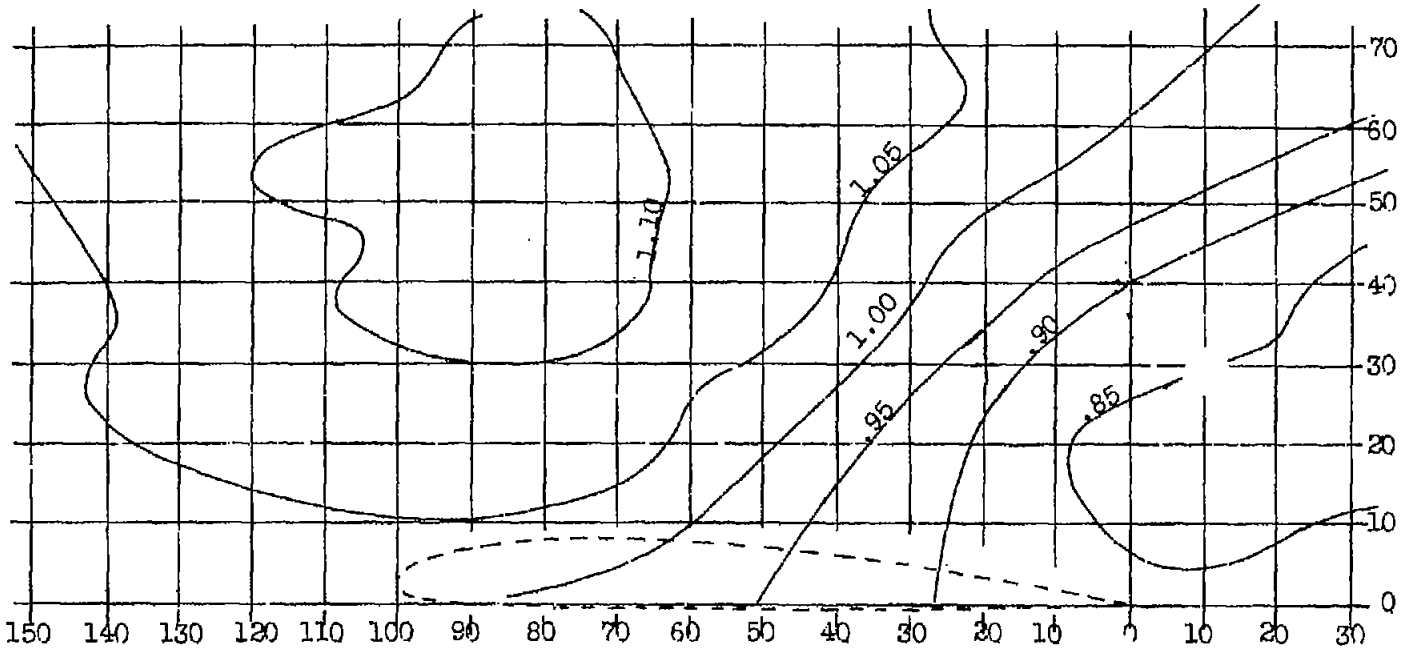


Figure 7.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.043 semispan outboard of wing tip. Coordinates in percentage of chord at station 0.036 semispan inboard of wing tip, chord, 3 ft. 5 15/32 in. Pitot axis parallel to wing chord. Contours of q/q_{true}, $\alpha = 15.9^{\circ}$, $C_L = 1.345$

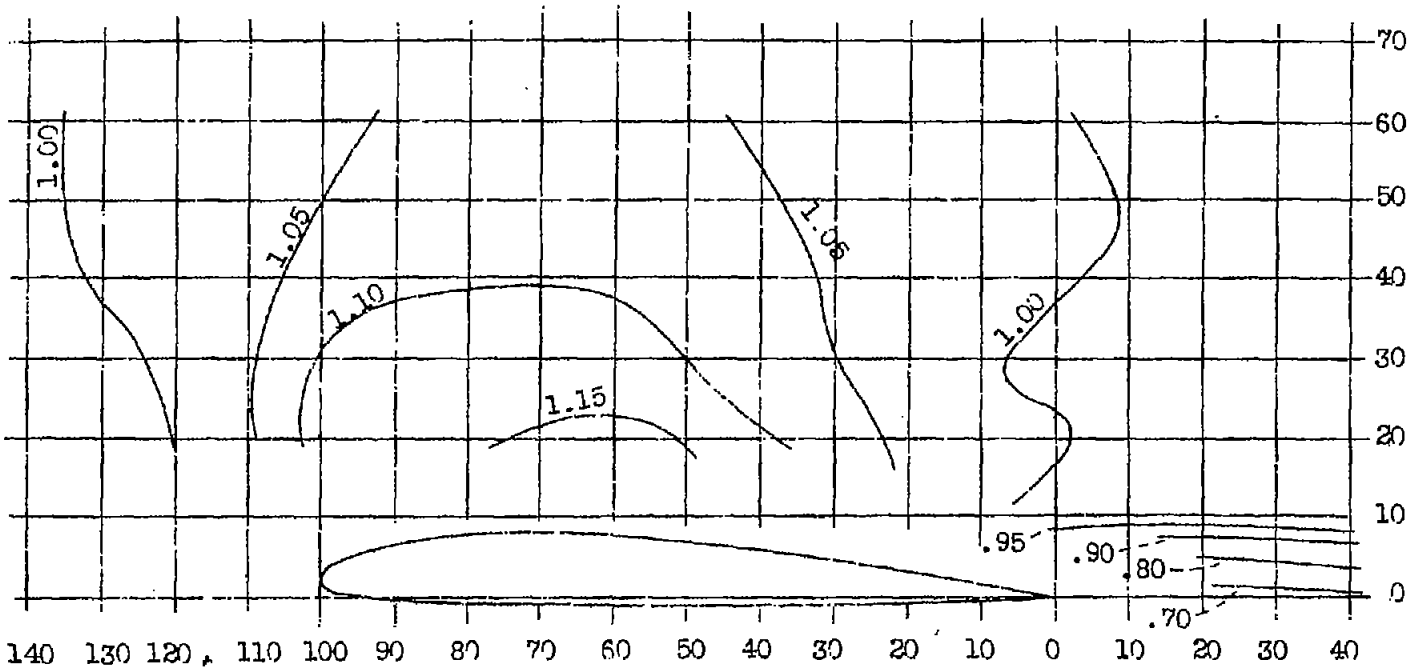


Figure 8.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.036 semispan inboard of wing tip. Chord at survey station: 3 ft. 5 15/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -0.4^{\circ}$, $C_L = 0.153$

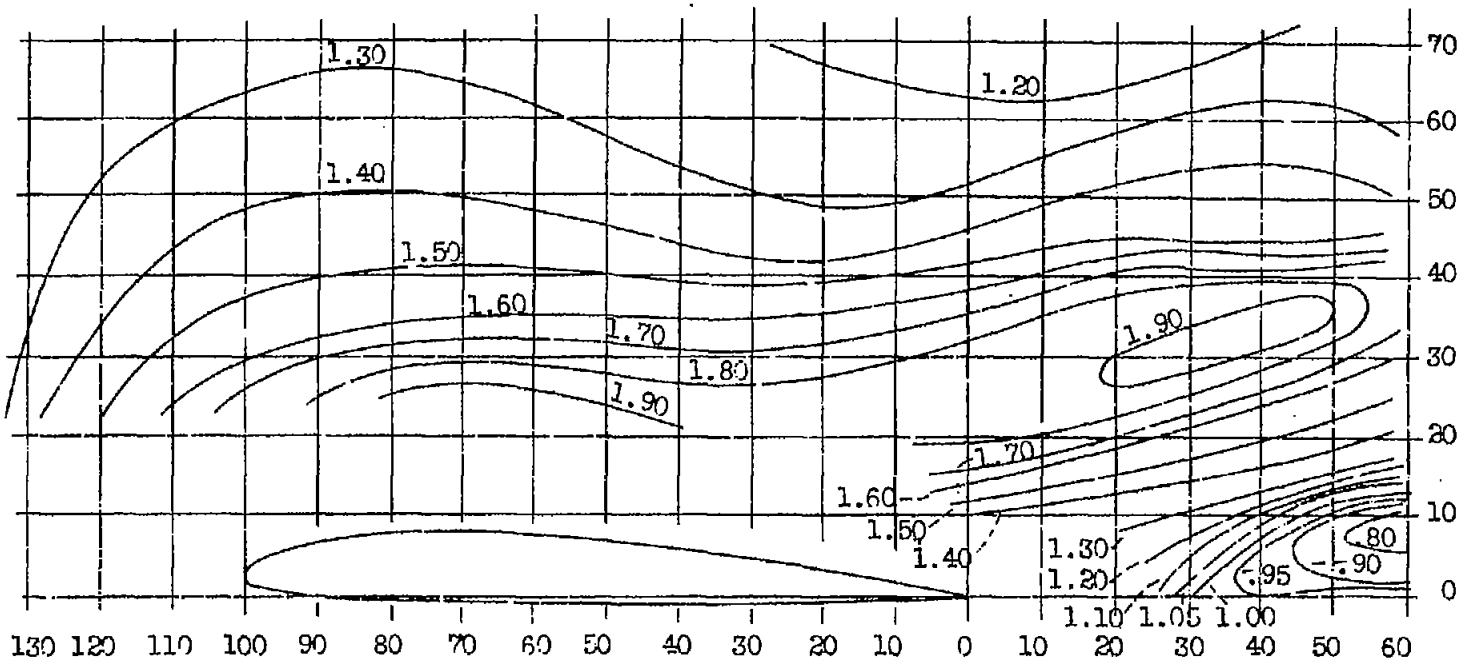


Figure 9.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.036 semispan inboard of wing tip. Chord at survey station: 3 ft. 5 15/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = 15.9^{\circ}$, $C_L = 1.345$

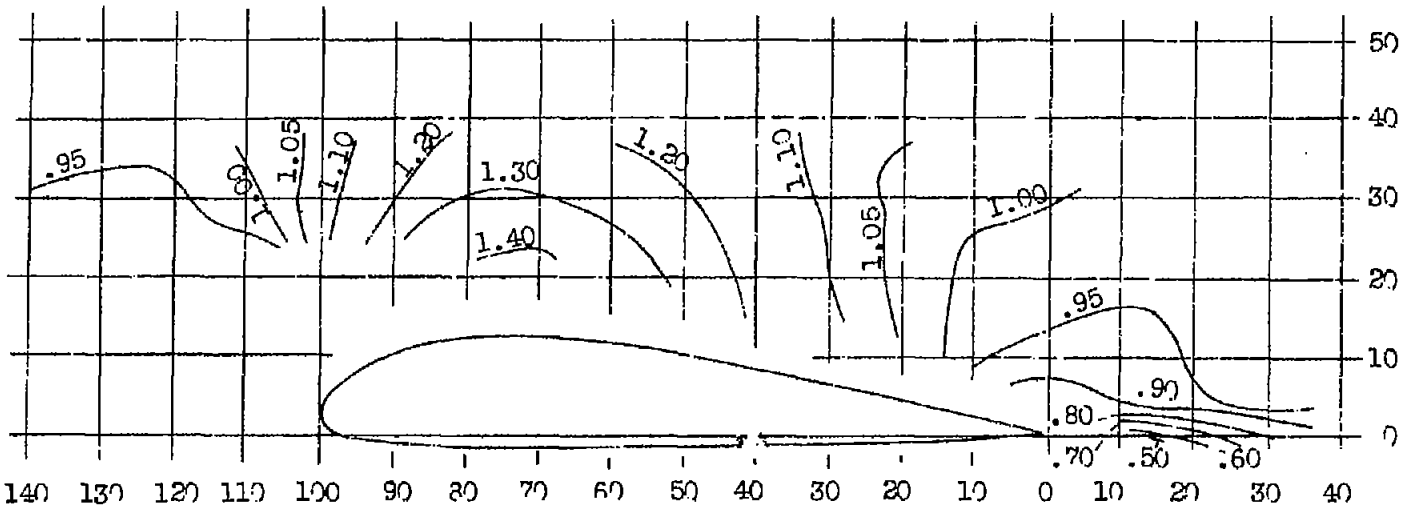


Figure 10.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.429 semispan inboard of wing tip. Chord at survey station: 8 ft. 3 13/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -0.4^{\circ}$, $C_L = 0.153$

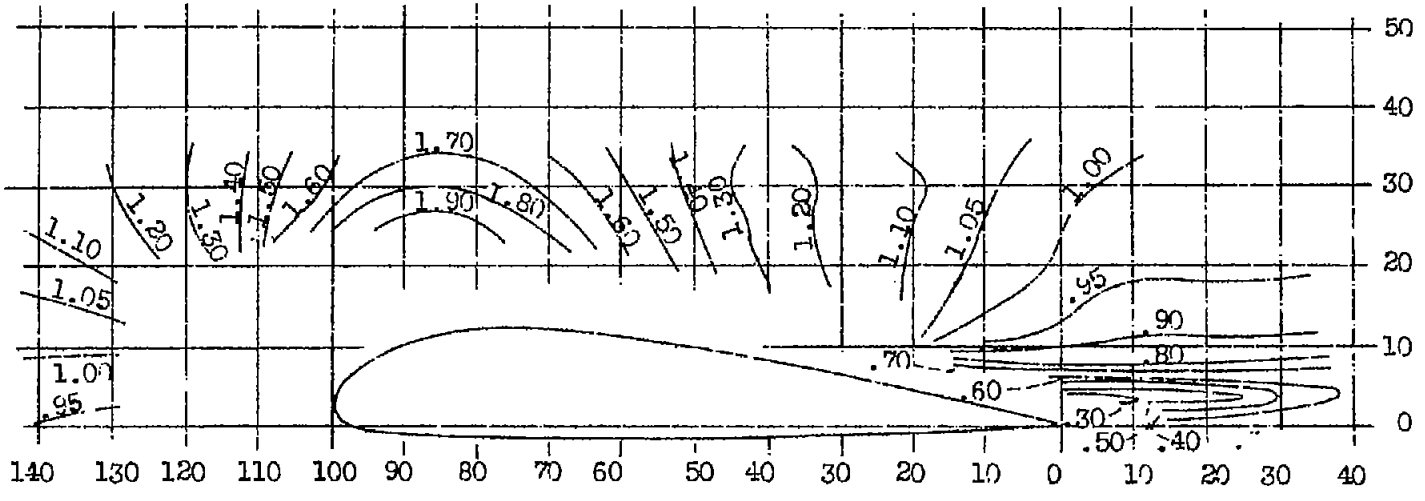


Figure 11.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.429 semispan inboard of wing tip. Chord at survey station: 8 ft. 3 13/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = 15.9^{\circ}$, $C_L = 1.345$

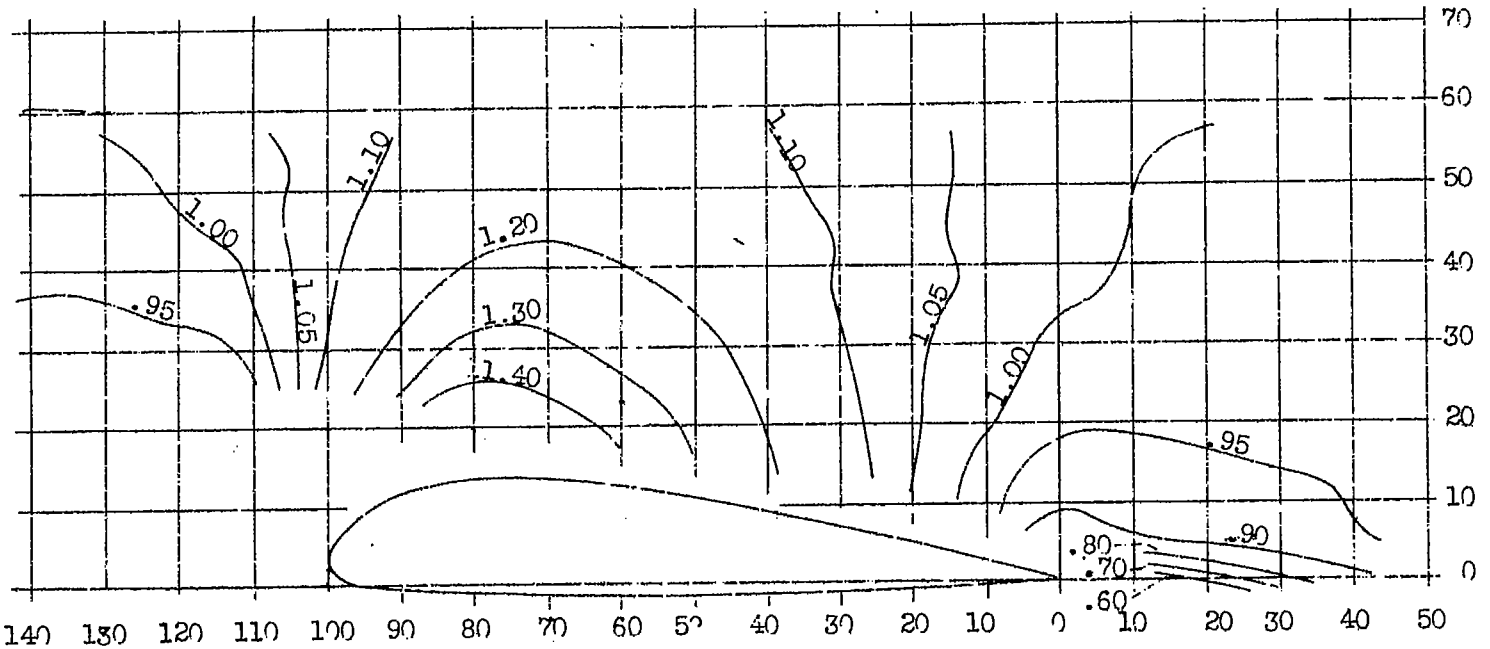


Figure 12.- 2:1 tapered U.S.A. 45 airfoil, 7.38 (mean chord) by 45.75 ft. Survey station: 0.432 semispan inboard of wing tip. Chord at survey station: 7 ft. 2 in. Pitot axis parallel to airfoil chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -0.5^{\circ}$, $C_L = 0.240$

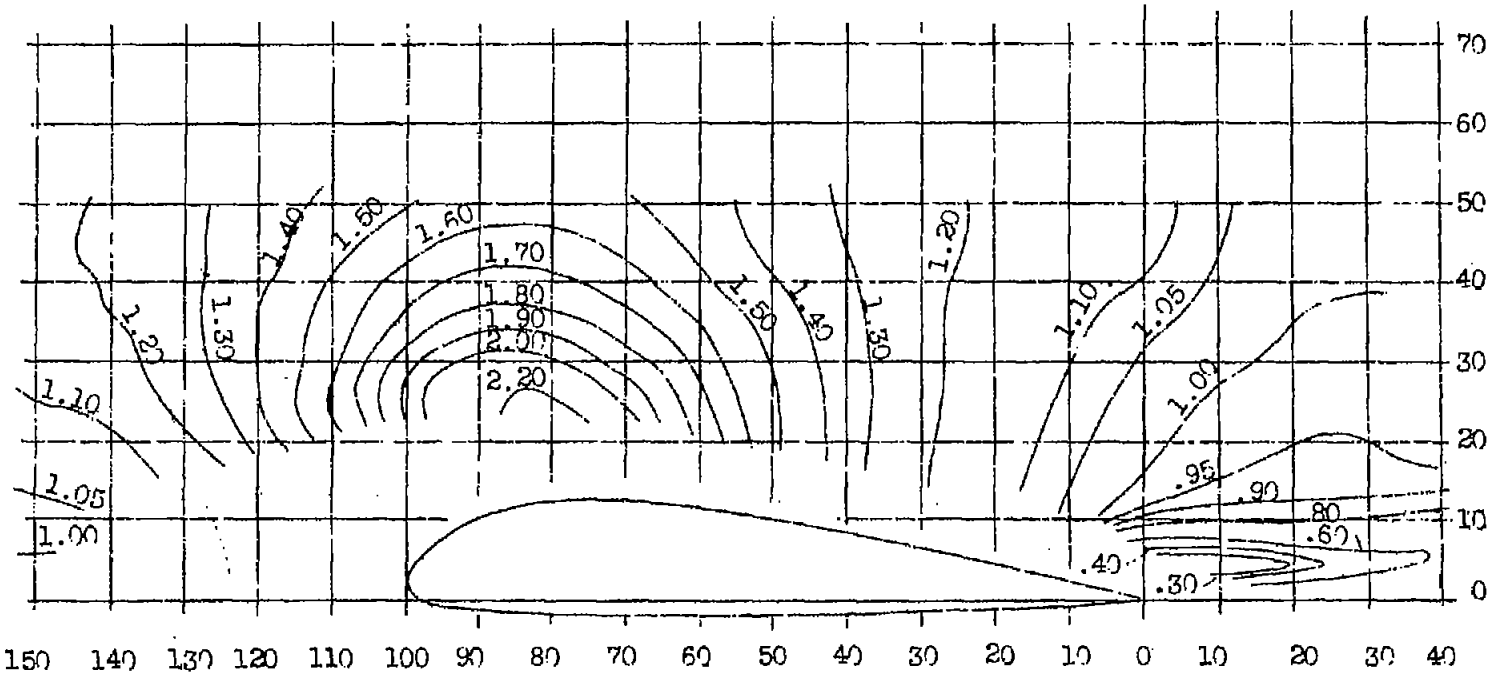


Figure 13.- 2:1 tapered U.S.A. 45 airfoil, 7.38 (mean chord) by 45.75 ft. Survey station: 0.432 semispan inboard of wing tip. Chord at survey station: 7 ft. 2 in. Pitot axis parallel to airfoil chord. Coordinates in percentage of chord. Contours of q_{true}/q, $\alpha = 16.3^{\circ}$, $C_L = 1.300$

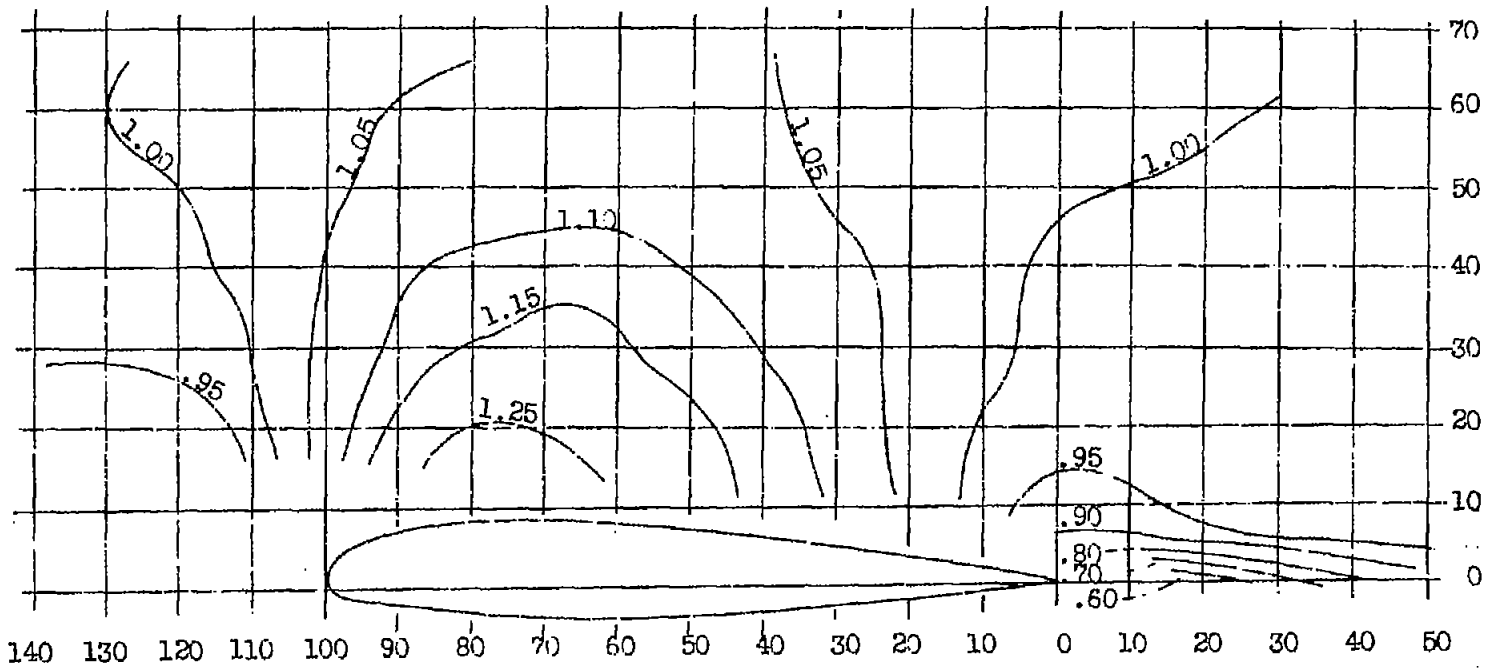


Figure 14.- Rectangular N.A.C.A. 23012 airfoil, 6 by 36 ft. Survey station: 0.389 semispan inboard of wing tip. Pitot axis parallel to airfoil chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -0.2^{\circ}$, $C_L = 0.070$

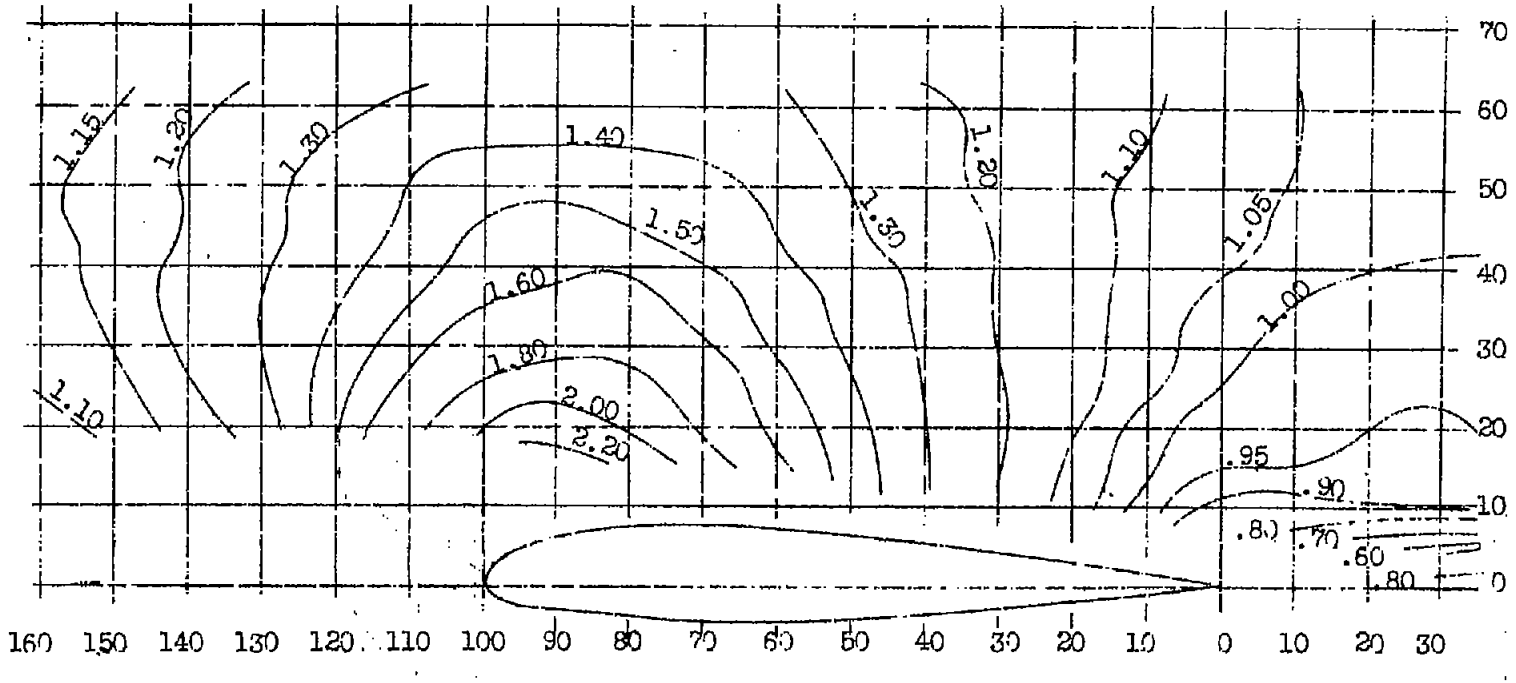


Figure 15.- Rectangular N.A.C.A. 23012 airfoil, 6 by 36 ft. Survey station: 0.389 semispan inboard of wing tip. Pitot axis parallel to airfoil chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = 17.1^{\circ}$, $C_L = 1.327$

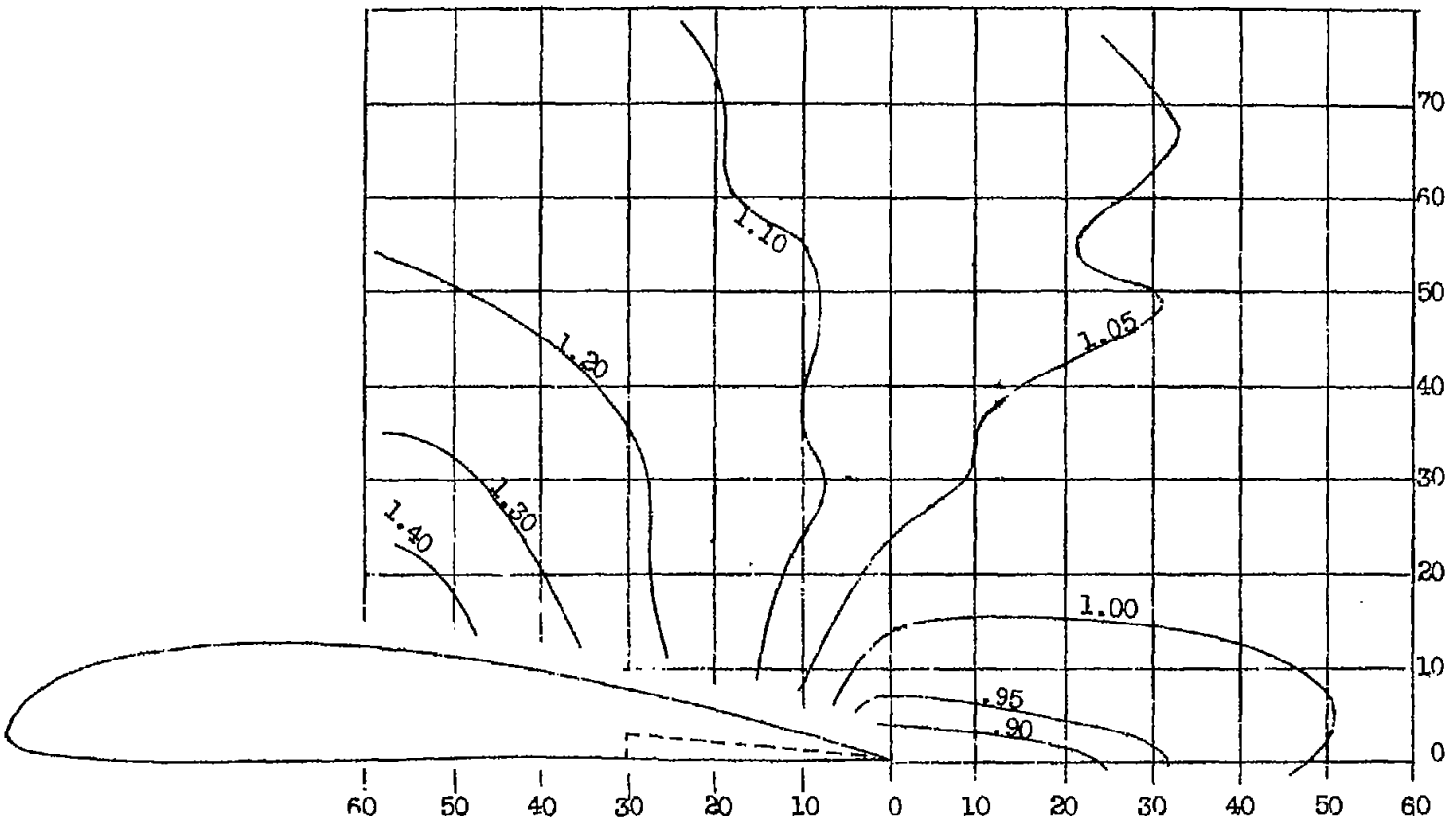


Figure 16.- Fairchild 22 with Zap flap. Wing: 5.21 (mean chord) by 32.83 ft., N-22 section profile, rectangular (rounded tip) form. Zap flap: chord, 1.65 ft., total flap area, 44.0 sq. ft., flap closed, $\delta_f = 0^\circ$, hinge axis at 70 percent chord. Survey station: 0.431 semispan inboard of wing tip. Chord at survey station: 5 ft. 6 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -0.8^\circ$, $C_L = 0.376$

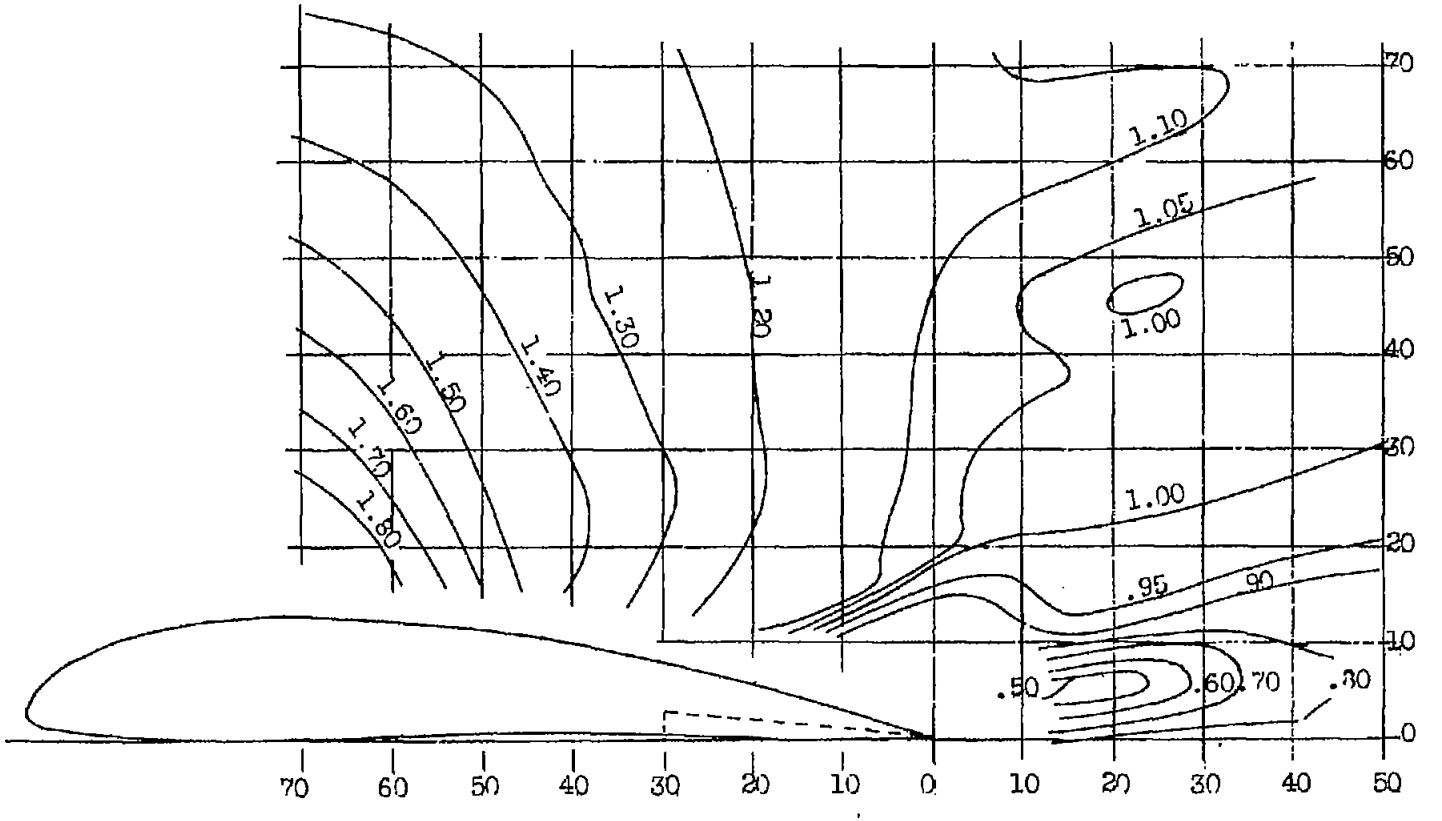


Figure 17.- Fairchild 22 with Zap flap. Wing: 5.21 (mean chord) by 32.83 ft., N-22 section profile, rectangular (rounded tip) plan form. Zap flap:chord, 1.65 ft., total flap area, 44.0 sq. ft., flap closed, $\delta_f = 0^\circ$, hinge axis at 70 percent chord. Survey station, 5 ft. 6 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = 17.0^\circ$, $C_L = 1.420$.

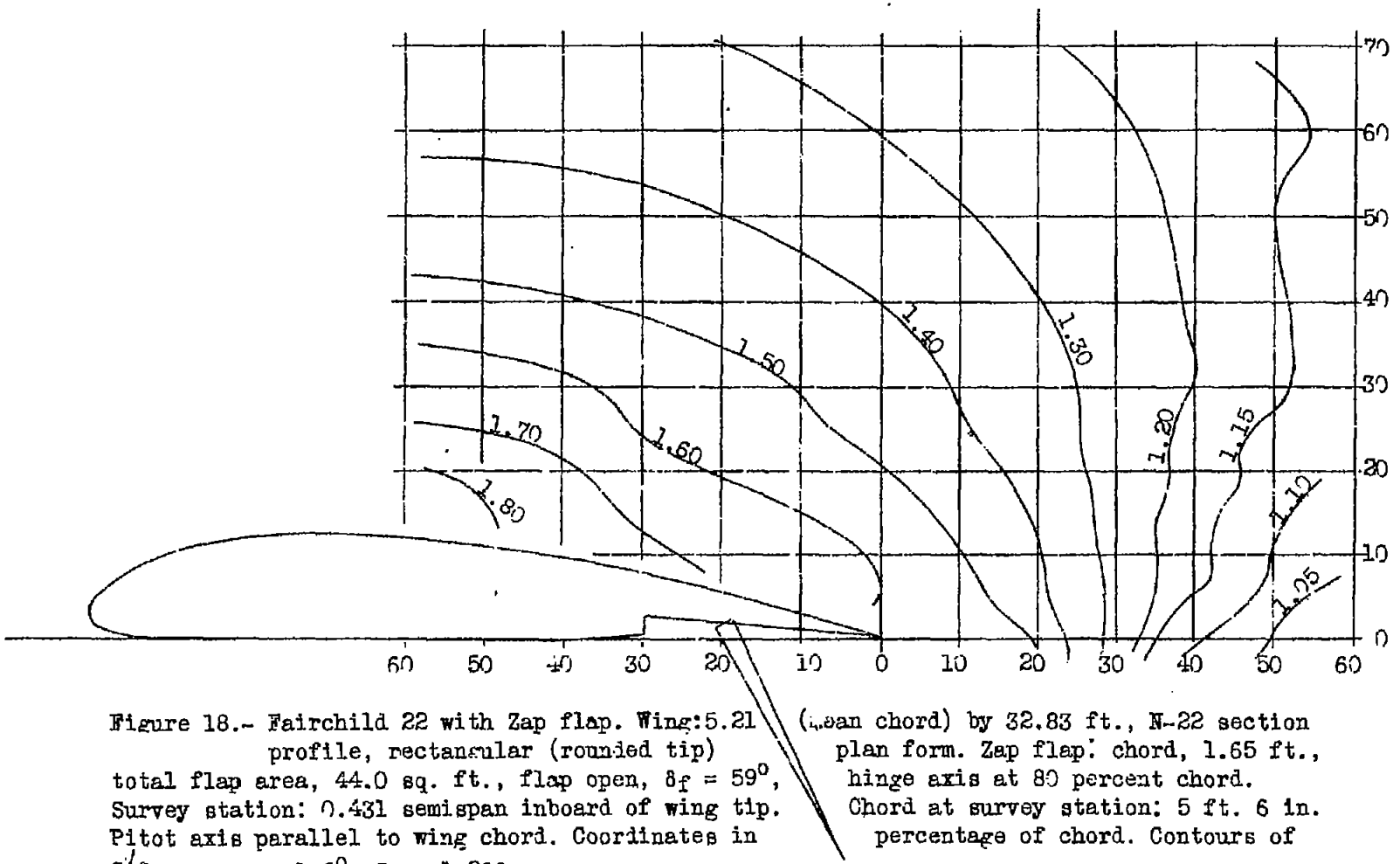


Figure 18.- Fairchild 22 with Zap flap. Wing: 5.21 (mean chord) by 32.83 ft., N-22 section profile, rectangular (rounded tip) plan form. Zap flap: chord, 1.65 ft., total flap area, 44.0 sq. ft., flap open, $\delta_f = 59^\circ$, hinge axis at 80 percent chord. Survey station: 0.431 semispan inboard of wing tip. Chord at survey station: 5 ft. 6 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = -1.9^\circ$, $C_L = 1.286$

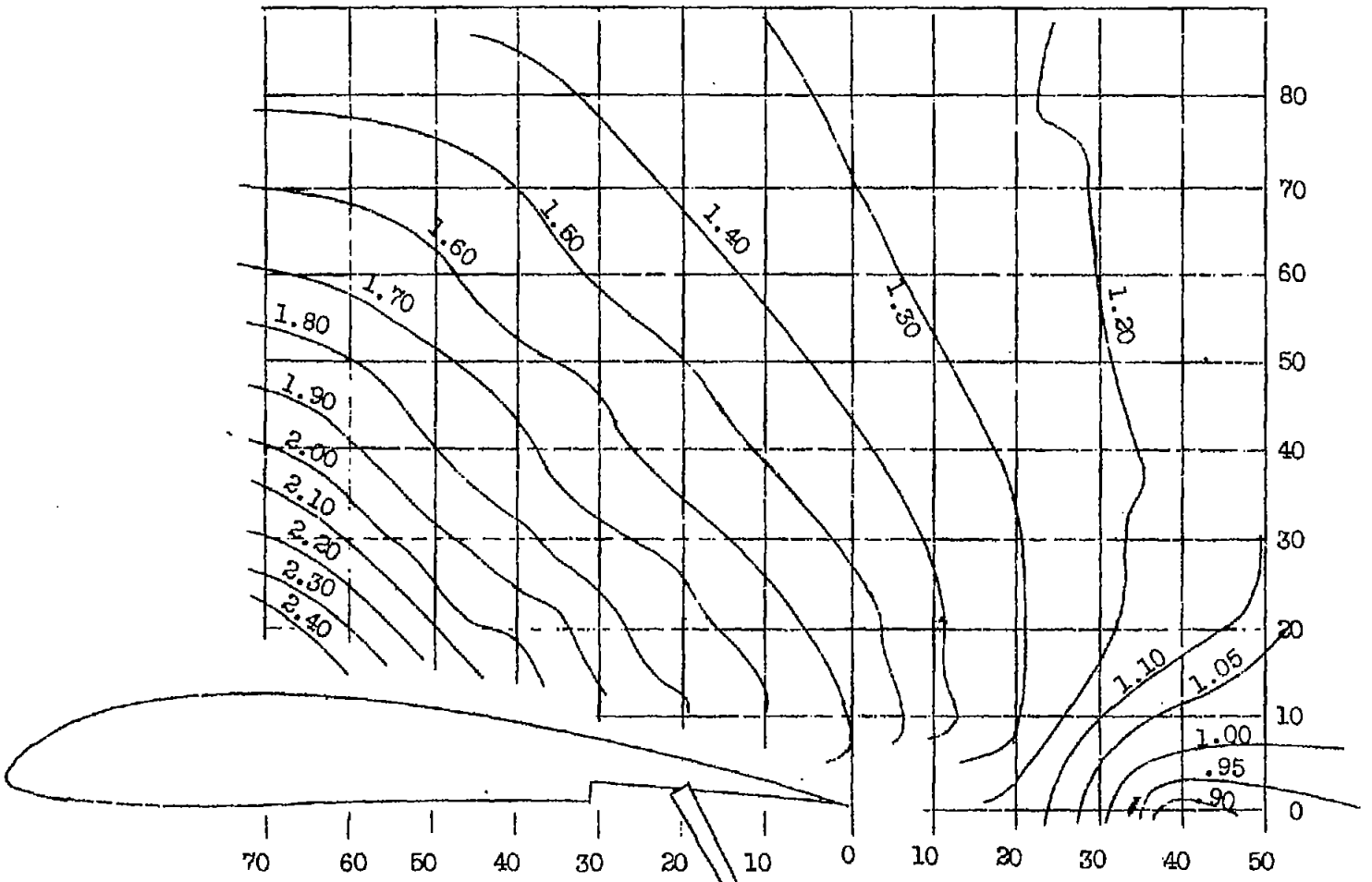
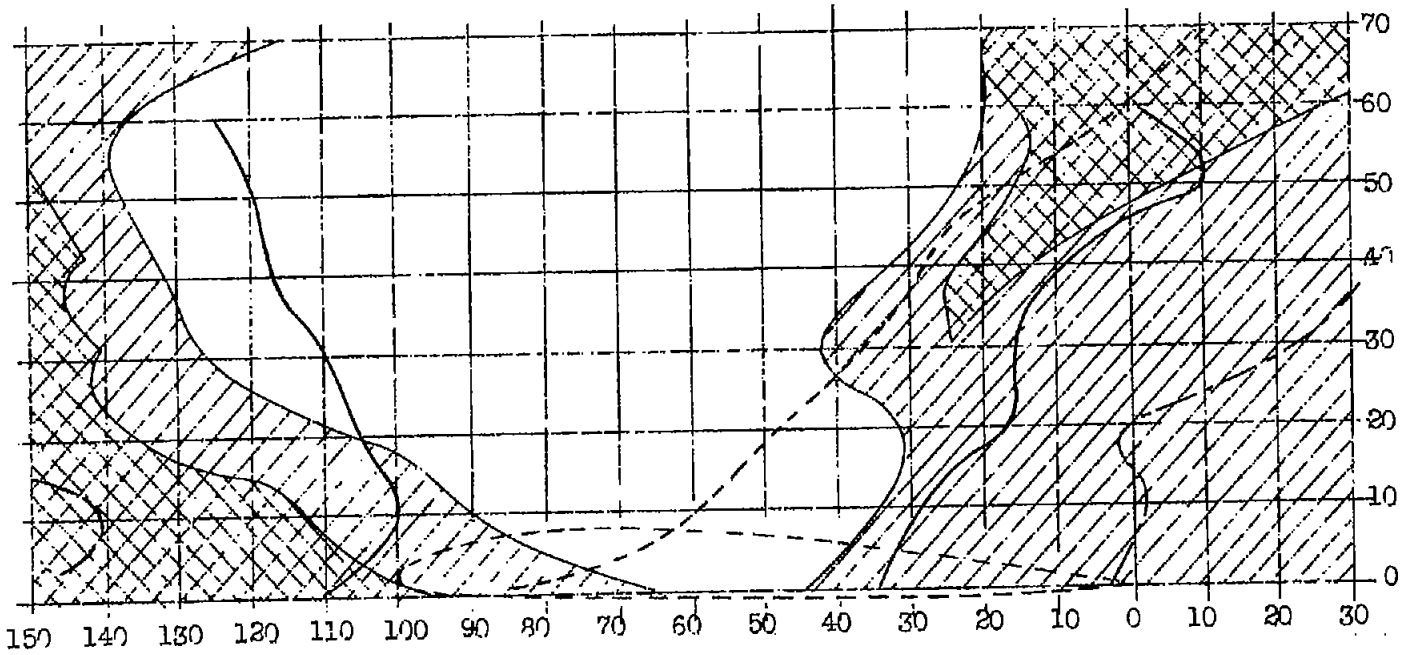


Figure 19.– Fairchild 22 with Zap flap. Wing, 5.21 (mean chord) by 32.83 ft., N-22 section profile, rectangular (rounded tip) plan form. Zap flap, chord, 1.65 ft. total flap area, 44.0 sq.ft., flap open, $\delta_f = 59^\circ$, hinge axis at 80 percent chord. Survey station, 0.431 semispan inboard of wing tip. Chord at survey station, 5 ft. 6 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord. Contours of q/q_{true}, $\alpha = 15.9^\circ$, $C_L = 2.380$

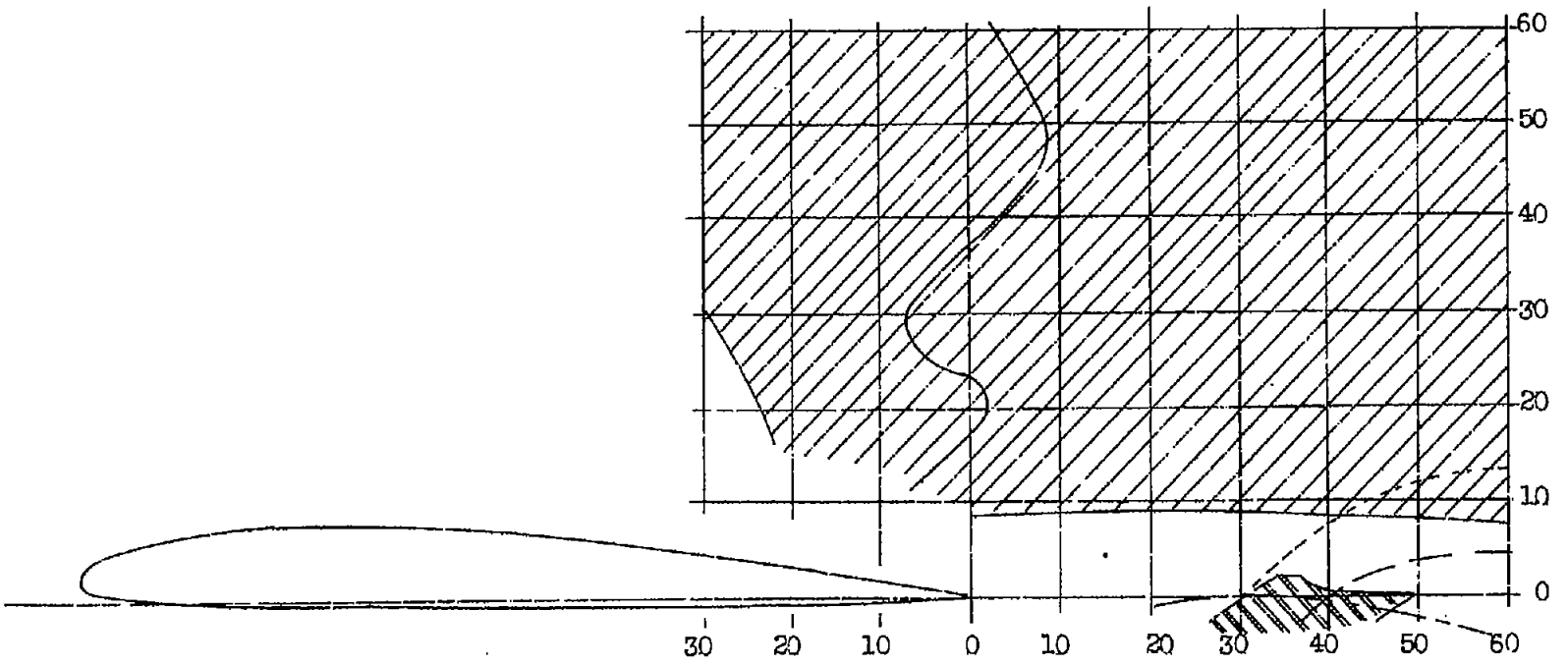


	q/q_{true}	α	C_L
———	1.00	-0.4°	0.153
— — —	1.00	4.7°	.540
—— - ——	1.00	10.7°	.989
- - - - - - - -	1.00	15.9°	1.345

q/q_{true} within ±5 percent of 1.00 at values of α -0.4° to 4.7°

q/q_{true} within ±5 percent of 1.00 at all values of α

Figure 20.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.043 semispan outboard of wing tip. Coordinates in percentage of chord at station 0.036 semispan inboard of wing tip. 3 ft. 5 15/32 in. chord. Pitot axis parallel to wing chord.

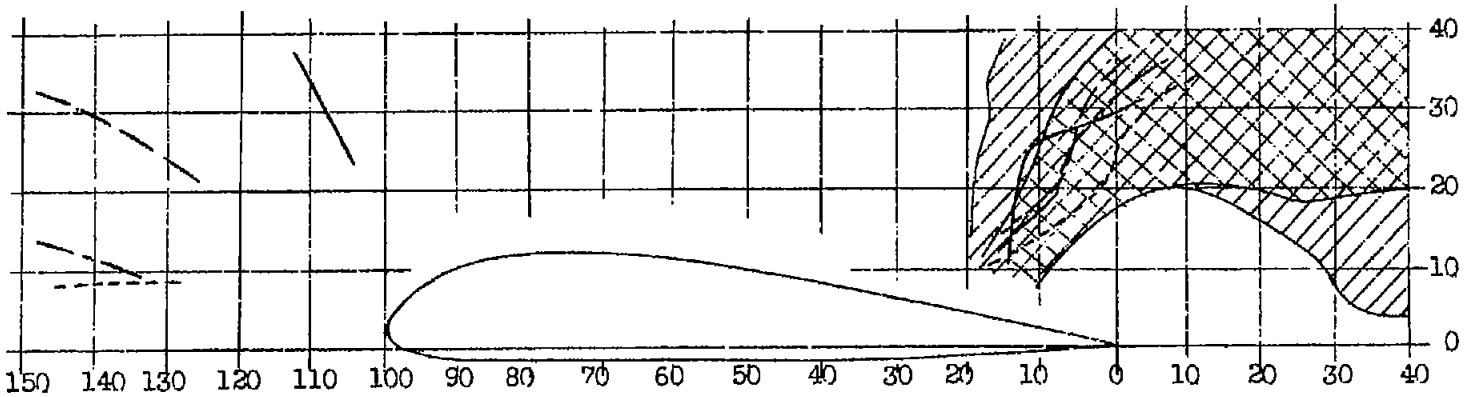


	q/q_{true}	α	C_L
———	1.00	-0.4°	0.153
— — —	1.00	4.7°	.540
— · —	1.00	10.7°	.989
- - - - -	1.00	15.9°	1.345

q/q_{true} within ±5 percent of 1.00 at α = -0.4°

q/q_{true} within ±5 percent of 1.00 at values of α , 4.7° to 15.9°

Figure 21.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.036 semispan inboard of wing tip. Chord at survey station: 3 ft. 5 15/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord.

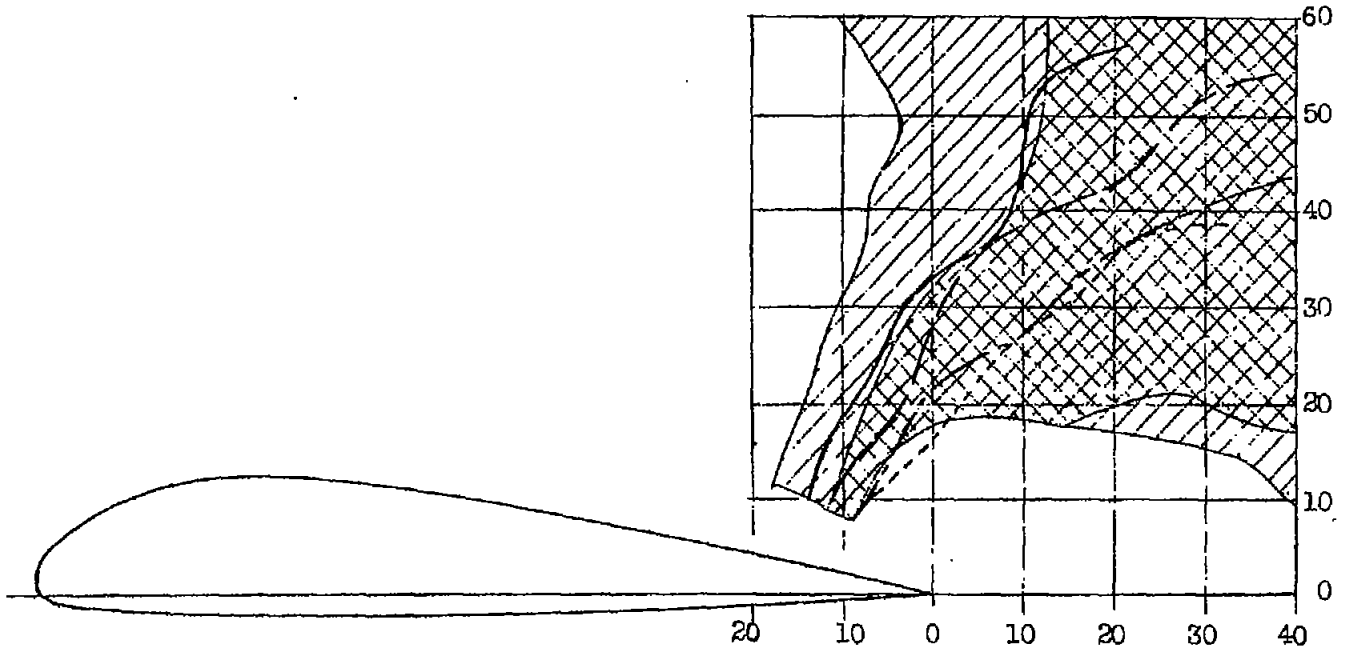


	q/q_{true}	α	C_L
———	1.00	-0.4°	0.153
— — —	1.00	4.7°	.540
——— — ———	1.00	10.7°	.989
- - - - - - - -	1.00	15.9°	1.345

q/q_{true} within ±5 percent of 1.00 at values of α , -0.4° to 4.7°

q/q_{true} within ±5 percent of 1.00 at all values of α

Figure 22.- YO-31A mock-up. Wing: 7.38 (mean chord) by 45.75 ft., U.S.A. 45 section profile, elliptical plan form. Survey station: 0.429 semispan inboard of wing tip. Chord at survey station: 8 ft. 3 13/32 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord.

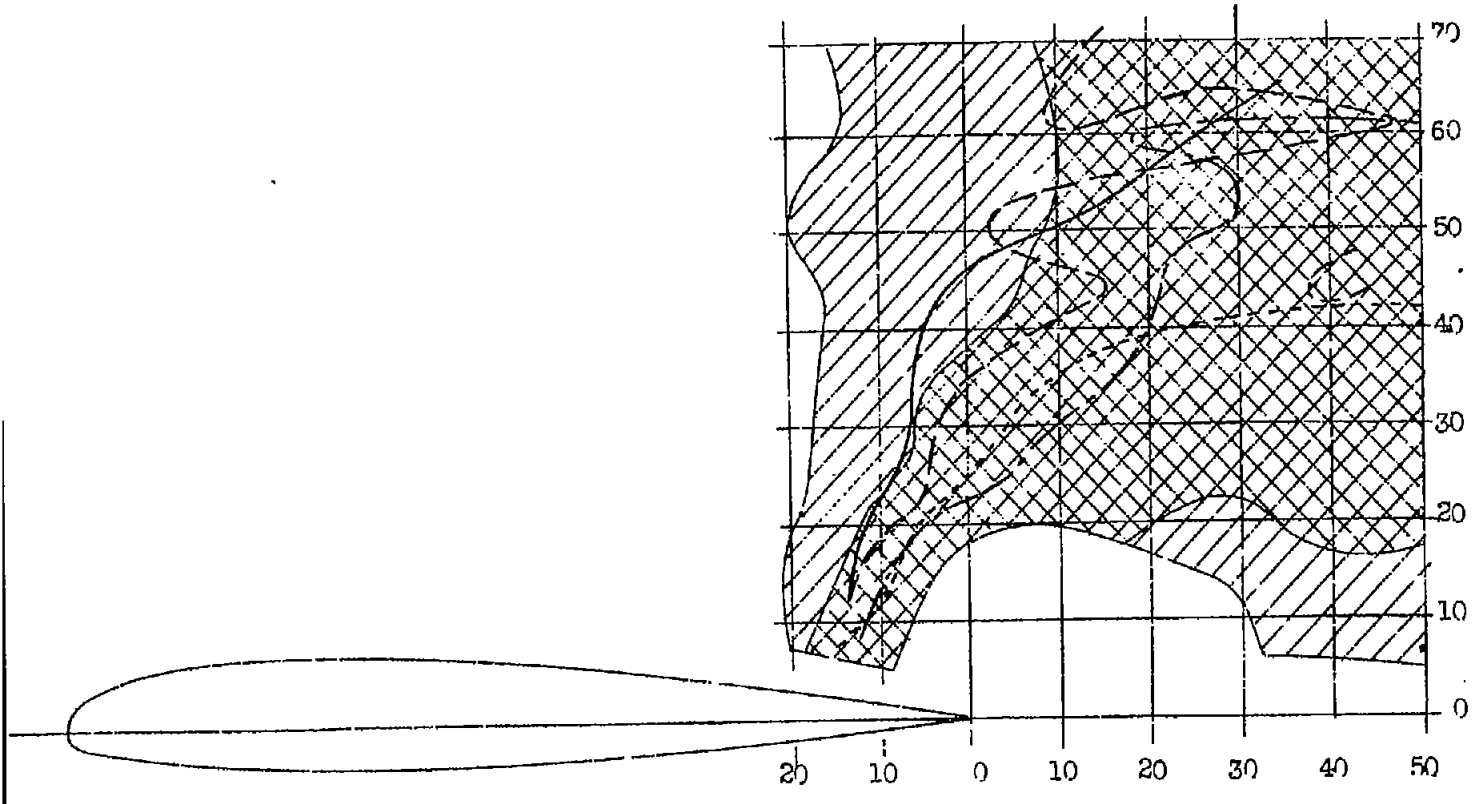


	q/q_{true}	α	C_L
———	1.00	-0.5°	0.240
— — —	1.00	4.7°	.612
—— · ——	1.00	10.8°	1.043
- - - - - - -	1.00	16.3°	1.300

q/q_{true} within ±5 percent of 1.00 at values of α, -0.5° to 4.7°

q/q_{true} within ±5 percent of 1.00 at all values of α

Figure 23.- 2:1 tapered U.S.A. 45 airfoil, 7.38 (mean chord) by 45.75 ft. Survey station: 0.432 semispan inboard of wing tip. Chord at survey station: 7 ft. 2 in. Coordinates in percentage of chord. Pitot axis parallel to airfoil chord.

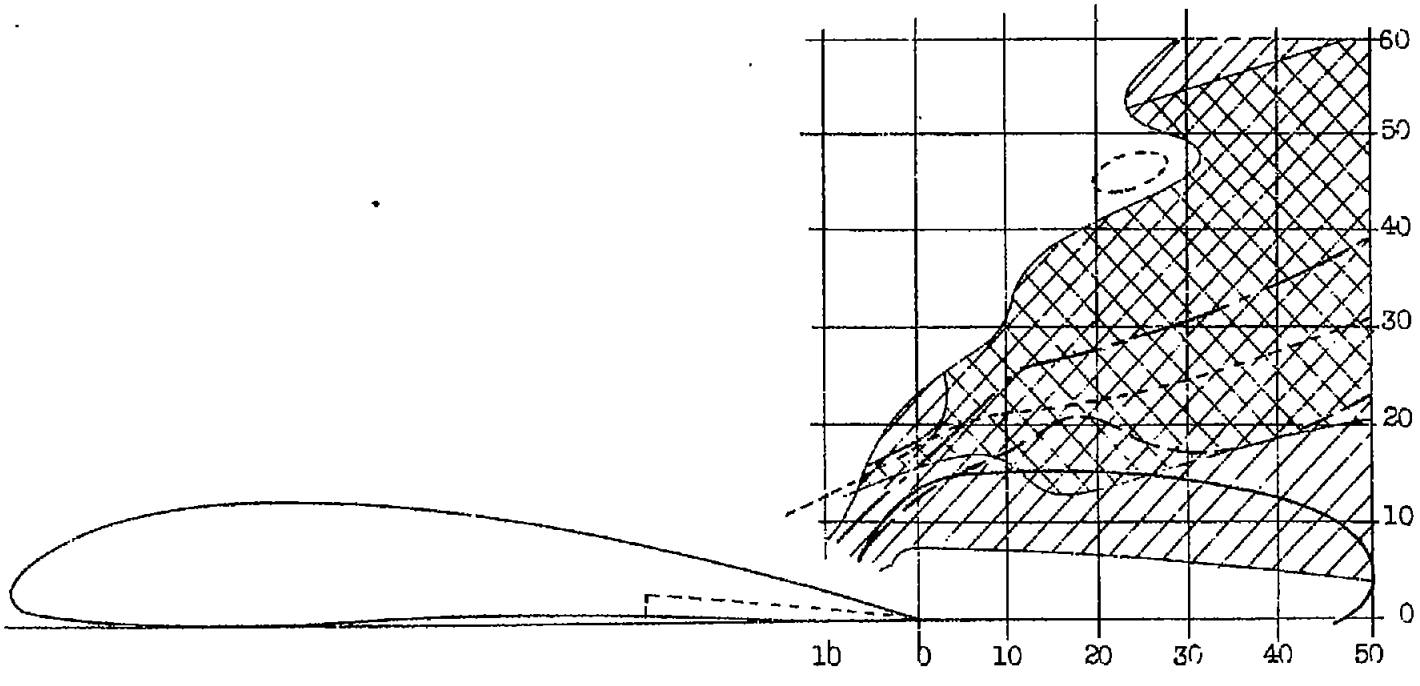


	q/q_{true}	α	C_L
———	1.00	-0.2°	0.070
— — —	1.00	5.3°	.466
—— - ——	1.00	11.6°	.940
- - - - - - -	1.00	17.1°	1.327

q/q_{true} within ±5 percent of 1.00 at values α , -0.2° to 5.3°

q/q_{true} within ±5 percent of 1.00 at all values of α

Figure 24.- Rectangular N.A.C.A. 23012 airfoil, 6 by 36 ft. Survey station: 0.389 semispan inboard of wing tip. Pitot axis parallel to airfoil chord. Coordinates in percentage of chord.



	q/q_{true}	α	C_L
———	1.00	-0.8°	0.376
— — —	1.00	4.7°	.770
— - —	1.00	11.2°	1.222
- - - - - - -	1.00	17.0°	1.420

q/q_{true} within ±5 percent of 1.00 at values of α, -0.8° to 4.7°

q/q_{true} within ±5 percent of 1.00 at all values of α

Figure 25.- Fairchild 22 with Zap flap. Wing: 5.21 (mean chord) by 32.63 ft., N-22 section profile, rectangular (rounded tip) plan form. Zap flap: chord, 1.65 ft., total flap area, 44.0 sq. ft., flap closed, $\delta_f = 0°$, hinge axis at 70 percent chord. Survey station: 0.431 semispan inboard of wing tip. Chord at survey station: 5 ft. 6 in. Pitot axis parallel to wing chord. Coordinates in percentage of chord.

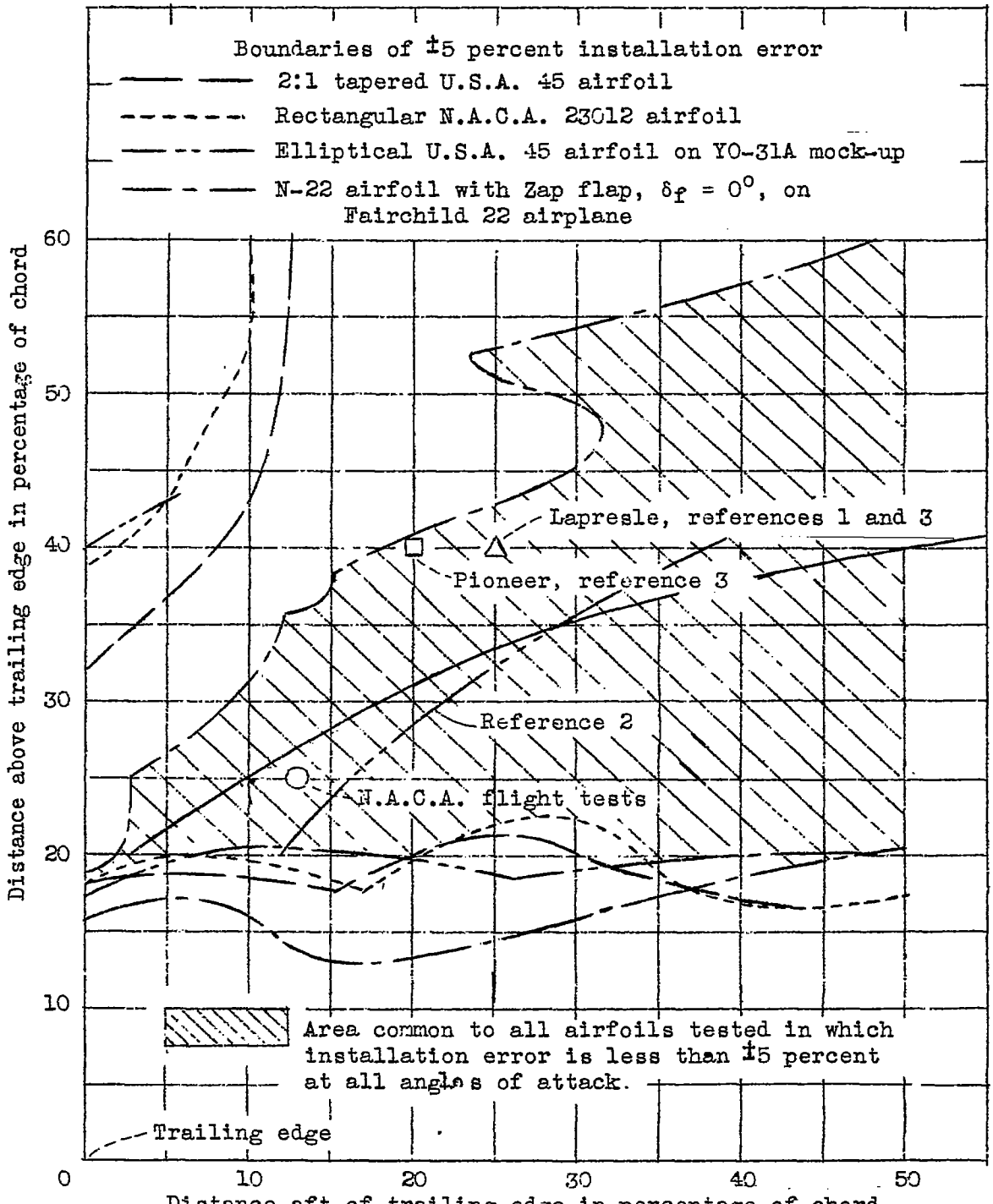


Figure 26.- Area for installation of the pressure element of an air-speed indicator on a monoplane at a section 40 percent of semispan inboard of wing tip.